

Spatial Use of Curleaff Mountain Mahogany by Bighorn Sheep Ewes and Lambs  
Related to Nutritional Quality and Escape Terrain: Final Report

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Multiple hypotheses have been proposed to explain sexual segregation in bighorn sheep. One hypothesis is that males segregate from maternal groups to avoid competing with their own offspring. Others suggest that rams and ewes with lambs may have different dietary requirements, or that ewes must be occupying sites closest to water due to greater need for it during lactation. However, studies of bighorn populations show that female groups almost always inhabit space with lower-quality forage, and that the closer proximity of female groups to water is independent of whether or not a ewe is lactating. The leading hypothesis that is most consistent with observations is that ewes and lambs, being smaller and more vulnerable to predation, will seek rough terrain with more escape routes to avoid predation. This usually means a trade-off between food quality and security for maternal groups.

It is currently thought that bighorn sheep forage in the landscape opportunistically within proximity to areas of suitable escape terrain. If a positive feedback relationship between browsing and re-growth or palatability exists, then foraging patches will be used differentially. Re-growth and palatability should be positively related to nutrition, as new growth is expected to have higher levels of crude protein and lower amounts of fiber. Knowing this relationship is needed to better understand habitat use and, ultimately, the reality of carrying capacity expectations of ungulates.

Rocky Mountain bighorn sheep (*Ovis canadensis*) in the Pryor Mountains and Bighorn Canyon National Recreation Area do not use the curleaf mountain mahogany habitat type in its entirety, though it has been identified as most important to this population. It has been hypothesized that the nutritional quality of curleaf mountain mahogany is lower in the unused areas even though escape terrain is suitable. The

goal of this work was to develop a mathematical model based on habitat and nutritional data that predicted spatial use of bighorn sheep in curleaf mountain mahogany habitat. Specifically, I tested the following:

Ho1: Bighorn sheep ewes and lambs use areas with greater escape terrain and greater nutritional quality.

Ha1: Bighorn sheep ewes and lambs use areas with greater escape terrain regardless of the nutritional quality.

Ha2: Bighorn sheep ewes and lambs use areas with greater nutritional quality regardless of the escape terrain.

Ha3: Bighorn sheep ewes and lambs use areas randomly.

## Methods

The study area, about 350 km<sup>2</sup> in size, was centered in the Bighorn Canyon National Recreation Area (BCNRA) and Pryor Mountains located in Montana and Wyoming (45°00' N, 108°20' W). BCNRA and the Pryor Mountains consist mainly of a cool, arid climate, with an average summer temperature of 21.1°C and average summer precipitation of 2.13 cm. The main feature of the BCNRA is the Bighorn Canyon. In the study area the Bighorn Canyon ranges in depth from 10 m to more than 300 m, having vertical slopes and broken cliffs throughout. Habitat consists of various woodlands, shrublands, and grasslands. Dominant woodlands were juniper/mountain mahogany and coniferous woodland, which consisted of Utah juniper (*Juniperus osteosperma*), curleaf mountain mahogany (*Cercocarpus ledifolius*), limber pine (*Pinus flexilis*), ponderosa pine (*P. ponderosa*), douglas fir (*Pseudotsuga menziesii*), and a mix of spruce (*Picea* spp.) and fir (*Abies* spp.). Shrublands included desert shrubland which

consisted of saltbrush (*Atriplex* spp.), greasewood (*Sarcobatus vermiculatus*), and big sagebrush (*Artemisia tridentata*), and mixed desert shrubland which consisted of rubber rabbitbrush (*Chrysothamnus nauseosus*), shadscale (*Atriplex confertifolia*), big sagebrush, broom snakeweed (*Gutierrezia sarothrae*), bluebunch wheatgrass (*Agropyron spicatum*), fendler three-awn (*Aristida fendleriana*), and needle-and-thread (*Stipa comata*). Grasslands included sagebrush steppe which consisted of big sagebrush and black sagebrush (*Artemisia nova*) and basin grasslands consisted of blue grama (*Bouteloua gracillis*), bluebunch wheatgrass, broom snakeweed, needle-and-thread, Hooker sandwort (*Arenaria hookeri*), fringed sagewort (*Artemisa fringida*), and Hoods phlox (*Phlox hoodia*). Cottonwood (*Populus* spp.) dominated near river and stream margins. In summer there are very few mule deer (*Odocoileus hemionus*) that were sympatric with bighorns. However, bighorns were sympatric with feral horses (*Equus caballus*), as a portion of the BCNRA comprised the Pryor Mountain Wild Horse Range (Kissell et al. 1994).

Population data were collected from late May to late December 2010. Surveys of lambing areas were conducted by foot and boat. Ewes and lambs were located using visual scanning, binoculars, and spotting scopes. Bighorn sheep were identified by age (lamb, juvenile, adult) and sex, counted, and their locations recorded using a Global Positioning System unit, rangefinder, and compass. All location information was stored in a Geographic Information System (GIS; ArcGIS, ESRI, Redlands, CA) database.

Curlleaf mountain mahogany (CLMM) plants were randomly sampled at locations spaced approximately 200 m apart across the study area; emphasis was placed on areas where ewe-lamb groups were observed. A sample of 30-50 g of current annual

growth (CAG) from CLMM plants was collected from 3-5 plants nearest to each location across two seasons: Growing season (1 June through 15 August 2010) and the senescent season (16 August through 31 October 2010). CLMM plants were also sampled where bighorn sheep were observed foraging on it and where the CLMM was accessible. Plant samples were placed in paper bags and frozen until nutritional analyses could be conducted. Nutritional analyses were conducted by the Habitat Lab at Washington State University. Slope for each GPS location was obtained from a GIS and a 30 m digital elevation model. Visibility was measured 25 m in each cardinal direction from each used and random location using a density board.

Vegetation samples were shipped to the University of Arkansas at Monticello for processing for nutritional and near-infrared reflectance spectroscopy (NIRS) analyses. Samples were dried at 60° Celsius for 24 hours and ground using a Wiley mill so that pieces would pass through a 1 mm sieve. Samples were divided into two subsamples. One subsample was sent to the Habitat Lab at Washington State University for wet chemistry analysis to determine percent crude protein and acid detergent fiber and the other subsample was analyzed using a NIRS 4500 spectroradiometer to obtain spectral data. WinISI software was used to model the relationship between wet chemistry laboratory results and spectral results for the purpose of predicting percent crude protein and acid detergent fiber samples.

Logistic regression was used to address the hypotheses. Maps of predicted percent crude protein, acid detergent fiber, and visibility were based on the interpolation of randomly sampled areas. Slope, predicted percent crude protein, and percent acid detergent fiber values were assigned to each bighorn sheep location where all data

were available. Known bighorn sheep locations were compared to random samples generated using Hawth's Tools in ArcGIS. Logistic regression analyses were conducted separately for the growing and senescent seasons to determine which factors were important to bighorn sheep use seasonally.

## Results

A total of 989 bighorn sheep on the western side of the Bighorn Canyon and 70 bighorn sheep on the eastern side of the Bighorn Canyon were observed from June to December 2010 (Table 1). Given the observations through time, a minimum number of ewes and lambs known alive was estimated between 50 and 60 at the end of the growing season. Ewes and lambs (and juvenile rams) ranged from the Crooked Creek Bay northward to Medicine Creek (Figure 1).

Table 1. Summary of the total number of ewes, lambs, adult rams, and juvenile rams observed from June to December 2010 on the Bighorn Canyon National Recreation Area located in north-central Wyoming and south-central Montana. Numbers do not represent individual animals, but total counts.

| Month     | Ewes | Lambs | Adult Rams | Juvenile Rams |
|-----------|------|-------|------------|---------------|
| June      | 49   | 24    | 3          | 16            |
| July      | 93   | 48    | 0          | 22            |
| August    | 98   | 58    | 7          | 20            |
| September | 84   | 47    | 12         | 22            |
| October   | 114  | 44    | 11         | 20            |
| November  | 96   | 48    | 15         | 16            |
| December  | 17   | 7     | 8          | 4             |
| Total     | 551  | 276   | 56         | 120           |

Mean group size ranged from 3.1 bighorns in December to 7.7 bighorns in November (Table 2). Mean group size across all months was 5.6 animals ( $\pm 1.7$  (1 S.D.)). The mean group size in June was different than the group size in July and November. Ewes lambled primarily during the first part of June and restricted their movements to the canyon. Ewes did not appear to leave the canyon until lambs were

about 1 month of age. After leaving the security of the canyon lambs did not form nursery groups as observed in the past (Kissell, personal observation). Instead, lambs were always observed to be close to their dams and groups were never far from escape terrain.

The mean number of lambs per 100 ewes was relatively stable until fall (Table 3). Fourteen individual lambs were known to be born during 2010. A maximum of 7 lambs were located during any given survey during the fall. One lamb and one ewe were observed coughing in the summer; however, the cause was not identified.

Table 2. Mean group size by month from June to December 2010 on the Bighorn Canyon National Recreation Area located in north-central Wyoming and south-central Montana.

| Month     | N  | Mean Group Size |
|-----------|----|-----------------|
| June      | 29 | 3.4             |
| July      | 25 | 7.1             |
| August    | 31 | 6.3             |
| September | 28 | 5.8             |
| October   | 35 | 5.5             |
| November  | 25 | 7.7             |
| December  | 11 | 3.3             |

Table 3. The lamb to ewe ratio (lambs per 100 ewes) by month from June to December 2010 on the Bighorn Canyon National Recreation Area located in north-central Wyoming and south-central Montana.

| Month     | N  | Lamb per 100 ewes |
|-----------|----|-------------------|
| June      | 29 | 50.0              |
| July      | 25 | 51.6              |
| August    | 31 | 59.2              |
| September | 28 | 56.0              |
| October   | 35 | 38.6              |
| November  | 25 | 50.0              |
| December  | 11 | 41.2              |

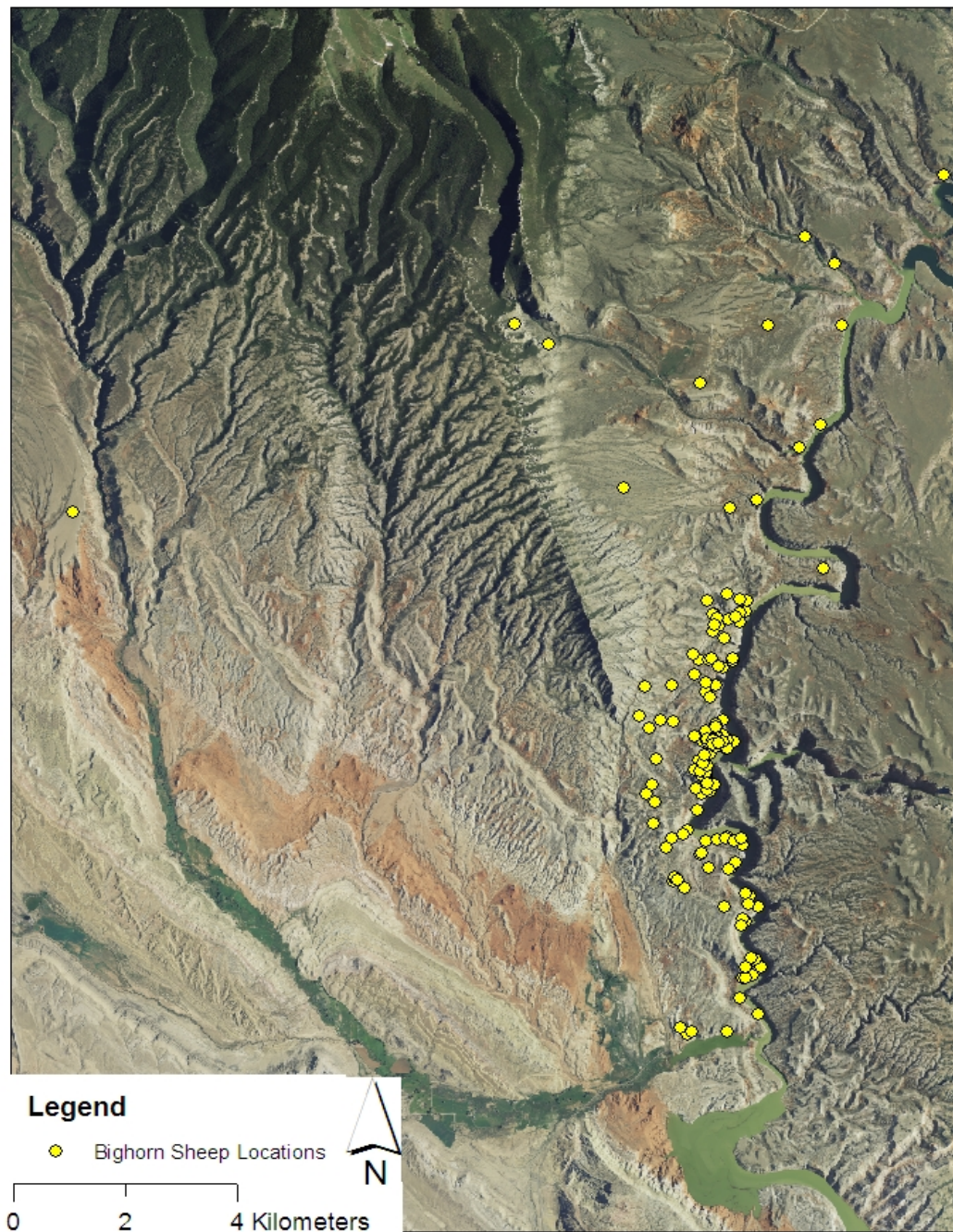


Figure 1. Bighorn sheep locations along the western side of the Bighorn Canyon and East Pryor Mountain from June to December 2010. The southernmost locations are adjacent to Crooked Creek Bay and the northernmost locations are in the Medicine Creek drainage.

Ewe-lamb groups were most often observed in escape terrain during the growth season; mean slope was 91.9%. A total of 89.9% and 86.7% of all observed sheep were within 300 m of escape terrain ( $\geq 60\%$  slope; Smith et al. 1991) during the growth and senescent seasons, respectively. Mean visibility in stands with CLMM was 50.1%.

Curleaf mountain mahogany, which was associated with escape terrain for ewe-lamb groups, was found to be dying in many of the stands used by the ewe-lamb groups. A total of 50.7% of the curleaf mountain mahogany was found to be dead or dying ( $n = 736$  plants). A sample was collected and analyzed by Dr. Linnea Skoglund, a plant pathologist with the Montana State University Extension Service. The cause of the mortality was not identified. A root rot-like fungus (*Cylindrocarpon* spp.) was found but was not identified as the cause of the observed mortality. Further investigation into the cause, distribution, and trend in mortality of the curleaf mountain mahogany is warranted.

CLMM was sampled at 155 random locations during the growing and senescent seasons (Figure 2). Effort was concentrated in those areas where ewe-lamb groups were observed. Because the cover type map was not 100% accurate, 18 additional sites (not shown in Figure 2) were sampled. Additionally, samples were collected where ewe-lamb groups were observed to be feeding on CLMM and it was accessible for collection. One hundred ninety-nine samples of curleaf mountain mahogany were collected from June through October, 2010. A total of 197 of the 199 samples were sufficient for wet lab analysis; two samples containers were broken in transit and were removed from analysis.

Percent crude protein declined and acid detergent fiber increased from June through October (Table 4). The mean percent crude protein during the growing season was 10.3% ( $\pm 2.09$  (1 SD),  $n = 98$ ), and 8.4% ( $\pm 1.43$ ,  $n = 99$ ) during the senescent season. The mean percent acid detergent fiber during the growing season was 37.7% ( $\pm 5.16$ ,  $n = 97$ ), and 42.1% ( $\pm 5.05$ ,  $n = 99$ ) during the senescent season. An inverse relationship between percent crude protein and acid detergent fiber existed ( $R^2 = 0.549$ , d.f. = 194,  $p < 0.00001$ ). Percent crude protein and acid detergent fiber varied spatially across the landscape during the growing (Figures 3 and 4) and senescent (Figures 5 and 6) seasons. Modified partial least squares (MPLS) regression provided the best models to predict percent crude protein and acid detergent fiber (Table 5). Models for both percent crude protein and acid detergent fiber accounted for  $> 95\%$  of the variation based on NIRS analyses.

Bighorn sheep were observed in areas during the growing season that had steeper slopes ( $\bar{x} = 91.5\%$ ,  $SE = 12.1\%$ ), lower percent crude protein ( $\bar{x} = 8.2\%$ ,  $SE = 0.09\%$ ), and greater visibility ( $\bar{x} = 41.2\%$ ,  $SE = 3.2\%$ ) in CLMM than random sites ( $W = 22.238$ , d.f. = 4,  $p = 0.0002$ ). Bighorn sheep were observed in areas during the senescent season that were related inversely to percent crude protein ( $\bar{x} = 8.1\%$ ,  $SE = 0.06\%$ ) and positively related to the percent visibility ( $\bar{x} = 40.5\%$ ,  $SE = 2.4\%$ ); slope and percent acid detergent fiber were not important to predicting use during the senescent season ( $W = 22.295$ , d.f. = 4,  $p = 0.0002$ ; Table 6). The logistic model correctly predicted use 81.6% and 77.1% of the time for the growing and senescent seasons, respectively.

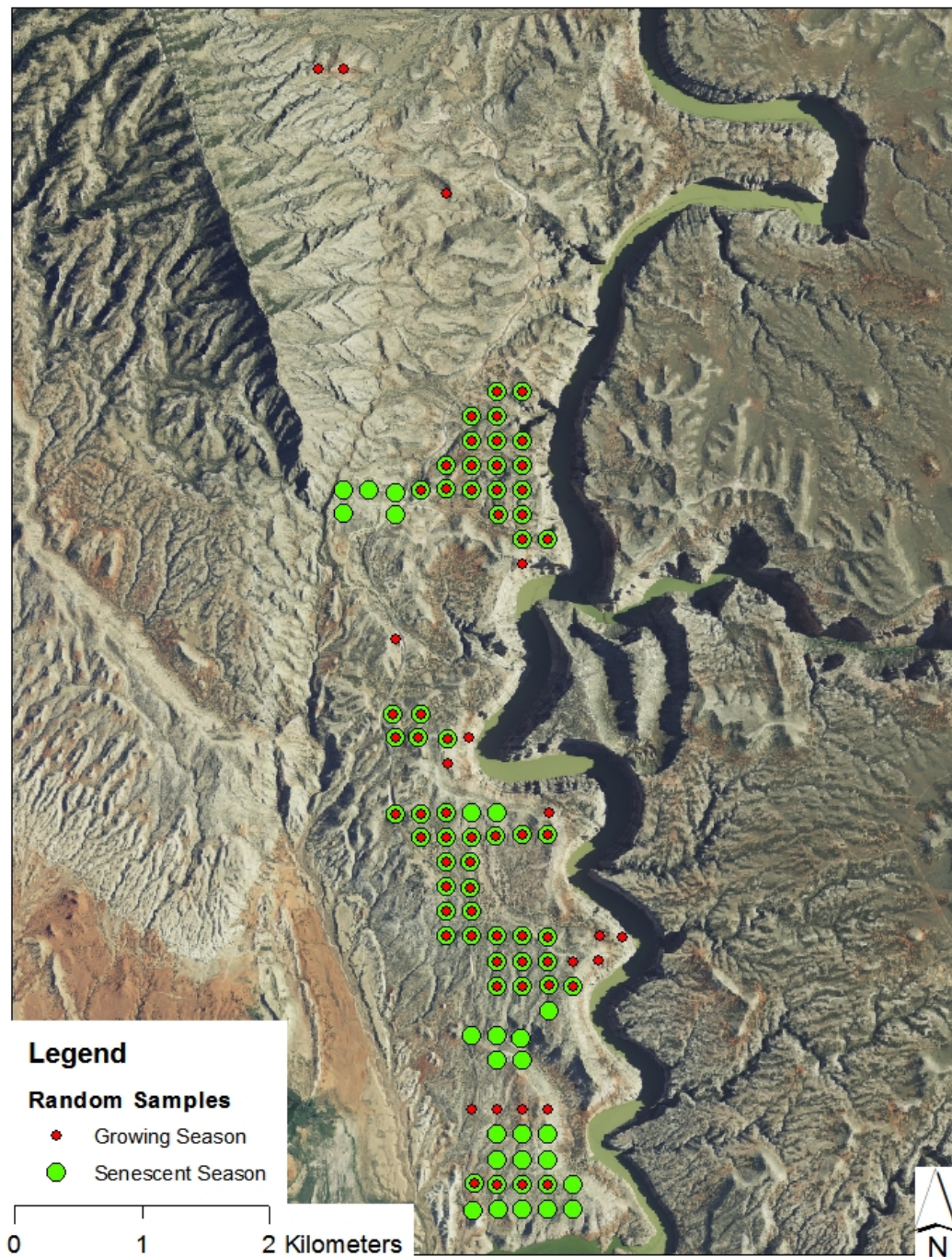


Figure 2. Random locations at which curleaf mountain mahogany was sampled during the growing and senescent seasons along the Bighorn Canyon and East Pryor Mountain from June to October 2010.

Table 4. Mean and standard deviation (in parentheses) of percent crude protein and acid detergent fiber for curleaf mountain mahogany (*Cercocarpus ledifolius*) from June through October 2010 in and adjacent to the Bighorn Canyon.

| Month     | Crude Protein | Acid Detergent Fiber | N   |
|-----------|---------------|----------------------|-----|
| June      | 11.1 (2.04)   | 36.7 (3.94)          | 46  |
| July      | 10.4 (1.07)   | 38.3 (1.60)          | 36  |
| August    | 8.5 (1.13)    | 41.9 (2.58)          | 39  |
| September | 8.7 (1.16)    | 43.0 (2.52)          | 42  |
| October   | 8.2 (1.12)    | 48.2 (3.24)          | 32  |
| Overall   | 9.5 (1.82)    | 40.3 (3.86)          | 195 |

Table 5. Results of NIRS-wet chemistry results for percent crude protein and acid detergent fiber from curleaf mountain mahogany from the Bighorn Canyon and Pryor Mountains in Montana and Wyoming.

|                      | Mean   | SEC <sup>a</sup> | R <sup>2</sup> | SECV <sup>b</sup> |
|----------------------|--------|------------------|----------------|-------------------|
| Crude Protein        | 9.679  | 0.404            | 0.955          | 0.000             |
| Acid Detergent Fiber | 39.994 | 0.888            | 0.951          | 0.000             |

<sup>a</sup>Standard error of calibration.

<sup>b</sup>Standard error of cross validation.

Table 6. Logistic regression results for predicting use of bighorn sheep ewe and lamb groups in the Bighorn Canyon and Pryor Mountains in Montana and Wyoming during the growing (1 June – 15 August 2010) and senescent (16 August – 31 October 2010) seasons. Crude protein and acid detergent fiber values were based on current annual growth of curleaf mountain mahogany (*Cercocarpus ledifolius*).

| Season    | Parameter            | D.F. | Estimate | Chi-square | P      |
|-----------|----------------------|------|----------|------------|--------|
| Growing   | Intercept            | 1    | 1.265    | 0.051      | 0.822  |
|           | Slope                | 1    | 0.015    | 11.758     | 0.0006 |
|           | Crude Protein        | 1    | -0.871   | 5.014      | 0.025  |
|           | Acid Detergent Fiber | 1    | 0.106    | 1.230      | 0.267  |
| Senescent | Intercept            | 1    | 6.150    | 1.287      | 0.257  |
|           | Slope                | 1    | 0.003    | 0.475      | 0.491  |
|           | Crude Protein        | 1    | -1.310   | 12.328     | 0.0004 |
|           | Acid Detergent Fiber | 1    | 0.101    | 1.307      | 0.253  |

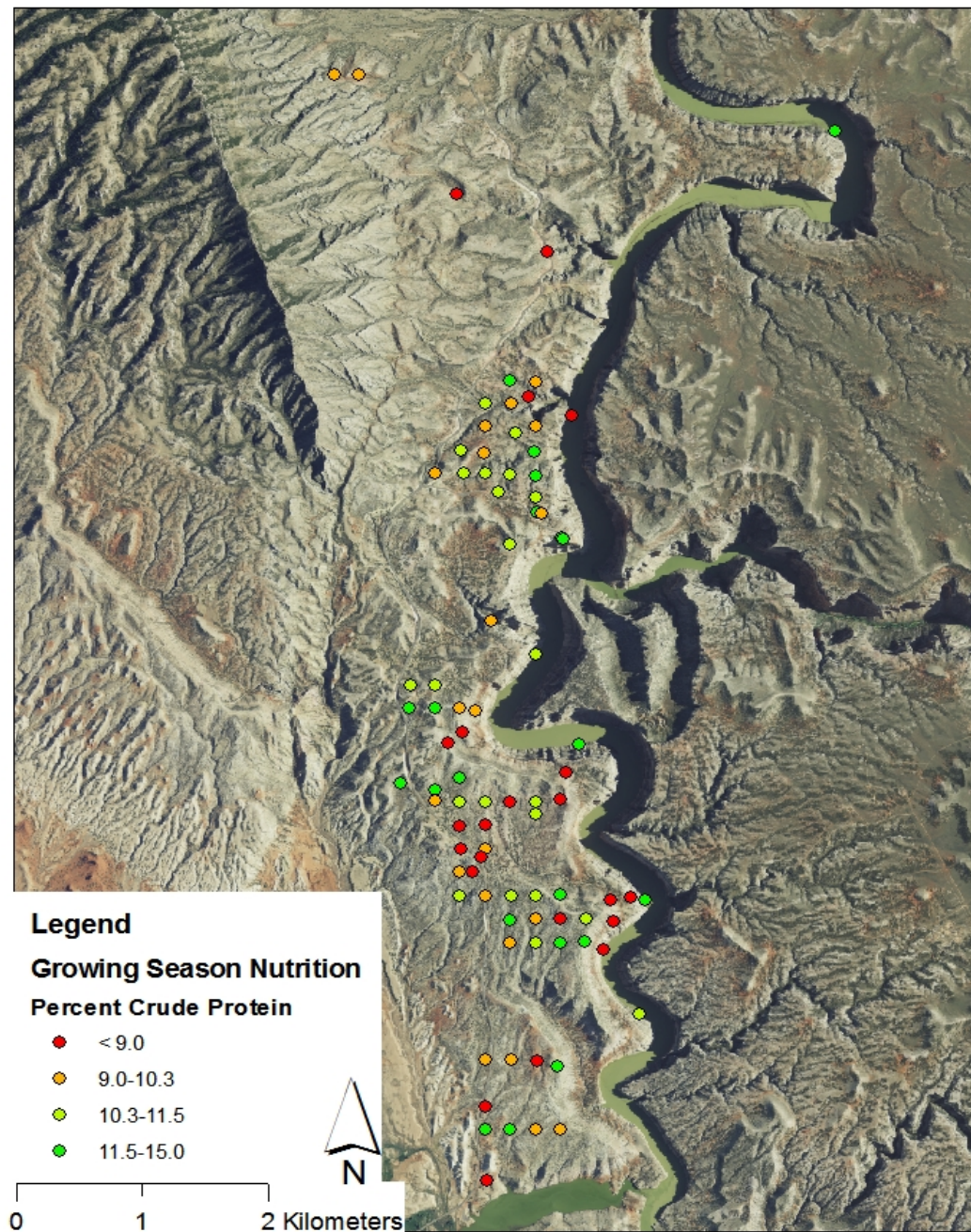


Figure 3. Spatial distribution of percent crude protein of curleaf mountain-mahogany (*Cercocarpus ledifolius*) during the growing season (1 June – 15 August 2010) in the Bighorn Canyon National Recreation Area.

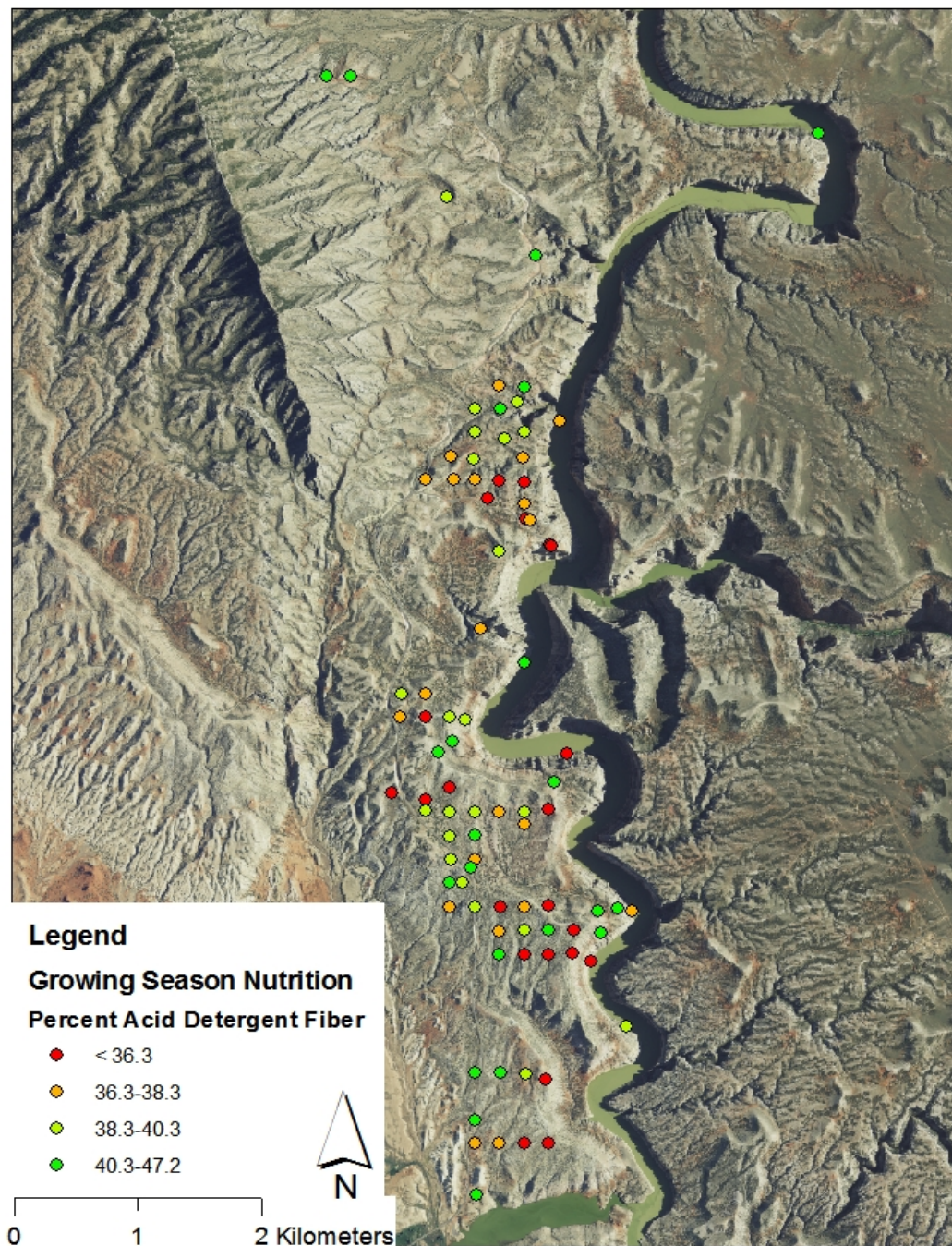


Figure 4. Spatial distribution of percent acid detergent fiber of curleaf mountain-mahogany (*Cercocarpus ledifolius*) during the growing season (1 June – 15 August 2010) in the Bighorn Canyon National Recreation Area.

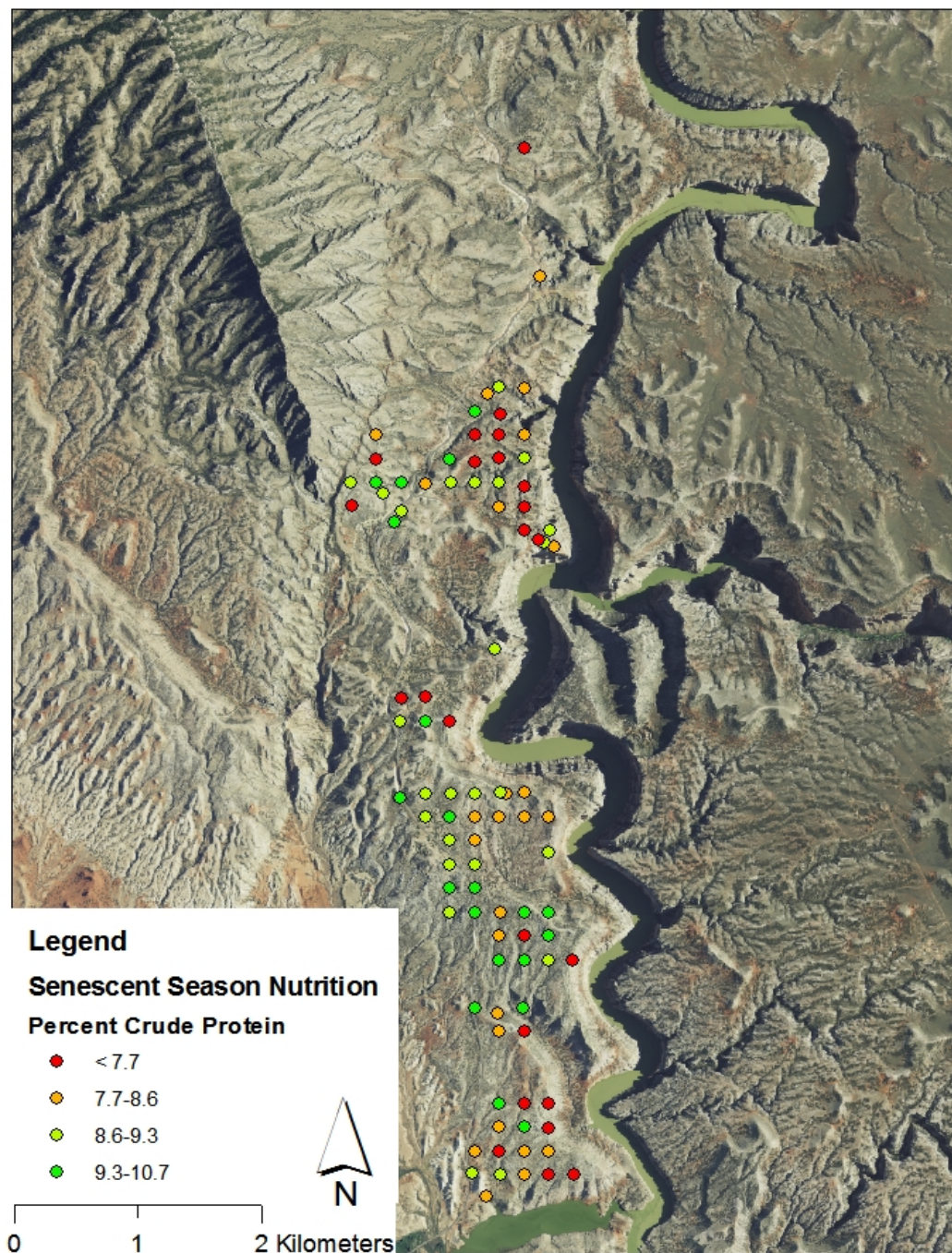


Figure 5. Spatial distribution of percent crude protein of curleaf mountain-mahogany (*Cercocarpus ledifolius*) during the senescent season (16 August – 31 October 2010) in the Bighorn Canyon National Recreation Area.

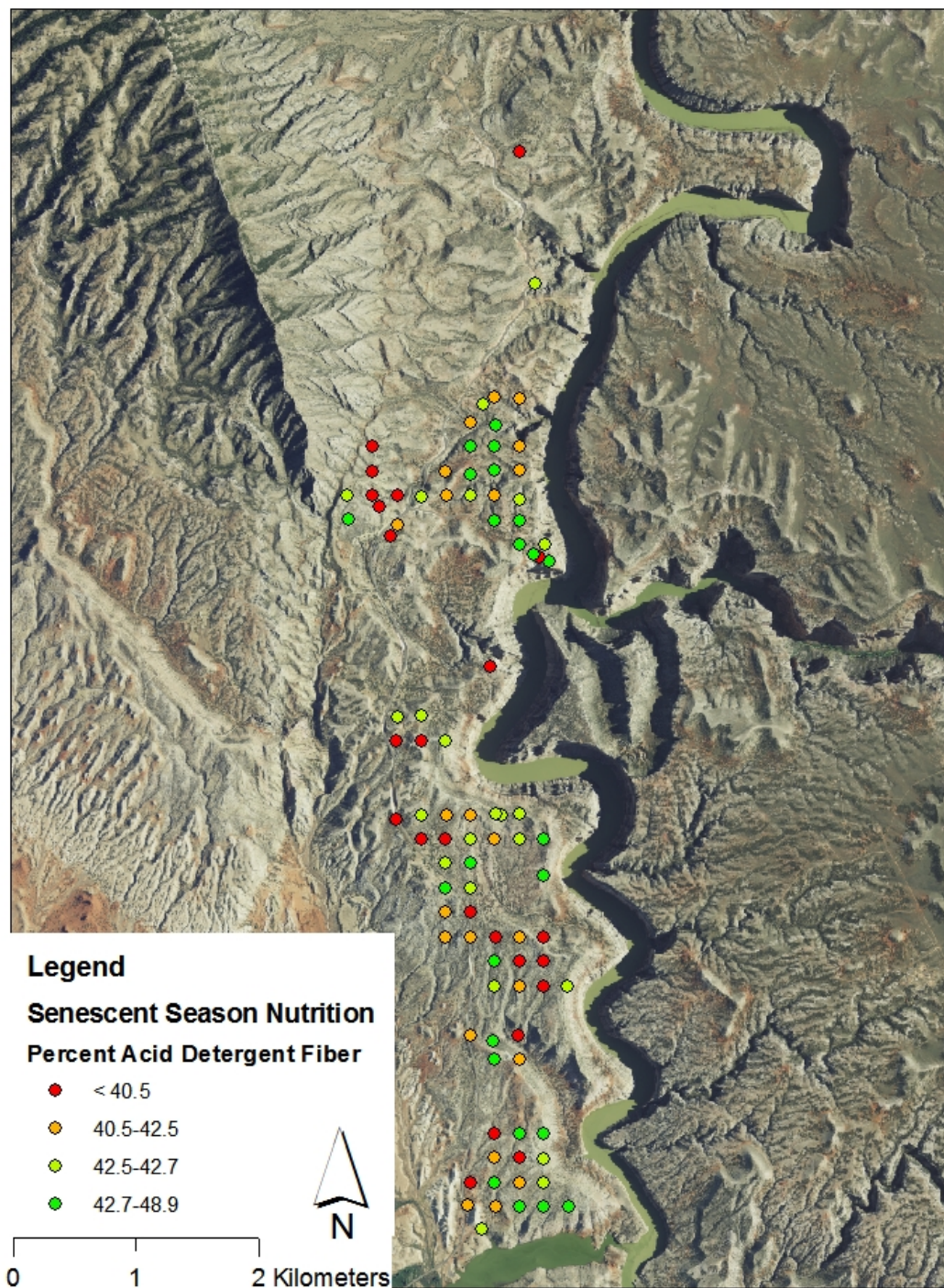


Figure 6. Spatial distribution of percent acid detergent fiber of curleaf mountain-mahogany (*Cercocarpus ledifolius*) during the senescent season (16 August – 31 October 2010) in the Bighorn Canyon National Recreation Area.

## Discussion

Roelle (2004) reported estimates of the bighorn sheep population to fluctuate from 47 to 115 animals from 1998 through 2003. Concurrent with those estimates, ram:100 ewe ratios also fluctuated (5.6-68.4 rams:100 ewes) as did lamb:100 ewe ratios (11.6 to 52.6 lambs:100 ewes). Montana Fish, Wildlife and Parks (2010) concluded that the Pryor Mountain bighorn sheep population was increasing in 2008 based on aerial counts. They observed a total of 78 sheep in 2008 with 46.5 rams:100 ewes, and 34.9 lambs:100 ewes. The number of lambs:100 ewes observed in this study was similar to that found by Roelle (2004) and the Montana Fish, Wildlife and Parks (2010).

A correction factor for the observations relative to the true population demographics and numbers was not estimated, so reported numbers should be considered as minimum values. The number of observations during December was lower because ice formed in the Bighorn Canyon and this precluded the use of a boat for surveying.

Bighorn sheep ewe and lamb groups used escape terrain at the expense of nutrition during both the growing and senescent seasons, a behavior described by the reproductive strategy hypothesis (Bleich et al. 1997). Ewe and lamb groups were located in escape terrain in areas with lower nutritional value than what occurred at random. Both slope and visibility were important in defining escape terrain during the growing season. The first alternative hypothesis, that bighorn sheep ewes and lambs use areas with greater escape terrain regardless of the nutritional quality, was accepted based on the logistic regression analysis; the other hypotheses were rejected.

Escape and nutritional factors, specifically percent visibility and crude protein, played a role in predicting use during the senescent season. Interestingly, slope played no role

in predicting the locations of bighorn sheep during the senescent season. Bighorn sheep may be making use of areas close to escape terrain, but just not in it, during the senescent season and those areas appear to have lower levels of crude protein.

Gudorf (2004) conducted a suitability study based on GIS data. She reported horizontal visibility by habitat type based on several habitat models. Using the model provided by Knight et al. (1987), horizontal visibility was reported to be 55% and 65% for Juniper/Mountain Mahogany/Limber pine woodlands, and mountain mahogany woodlands, respectively. Schoenecker et al. (2004) observed much greater visibility in the Dryhead area than was observed in this study. Differences in methodology and sampling were likely the reasons for the disparity in horizontal visibility. How mortality of CLMM affected the visibility was unknown; however, over time increased CLMM mortality is expected to increase visibility.

Monthly protein levels of CLMM during 2010 were similar to levels described by Duncan (1975) and Peterson (1999), but differed from results by Schoenecker et al. (2004). Peterson (1999) examined differences in protein content inside and outside exclosures across the Pryor Mountain Wild Horse Range from 1993 to 1995 and found an average of 10% crude protein levels across sites in June which declined to a low of 8.6% in November. Acid detergent fiber levels in this study exhibited an opposite trend compared to percent crude protein. However, Peterson (1999) found acid detergent fiber to be highest in August and lowest in November. Acid detergent fiber, a measure of digestibility, is expected to become greater as CAG ages. Schoenecker et al. (2004) found 9.41% ( $\pm 0.34\%$  SE) crude protein in CLMM in the winter which was greater than the level found in this study in the fall. The percent acid detergent fiber in this study was

also greater than that found by Schoenecker et al. (2004). Overall nutrition, based on percent crude protein and acid detergent fiber of CLMM, was poorer in this study. At least three possible reasons may explain the differences. First, different sampling frames, sampling distributions, and sample sizes were used in the two studies. Second, temporal variation in nutritional metrics is known to vary seasonally and annually. Third plant vigor may have declined due to factors causing the observed mortality, which have yet to be identified.

Little decadence of CLMM was observed in years past (Peterson 1999). The reported mortality of CLMM in this work was greater than previously reported for this site. Peterson (1999) concluded the CLMM stands appeared to be in good condition in 1993 and 1994. She indicated density was several times greater than that found in other studies (Duncan 1975, Schultz et al. 1991, Davis and Brotherson 1991) and attributed the greater density to reproduction. She indicated decadence was observed in several areas, but this was not quantified. The quantity of curleaf mountain mahogany is expected to decline given the current observed decadence and monitoring is recommended. In light of the observed mortality and such large differences over such a short duration, further investigation of CLMM nutrition is warranted.

Recently, advances have been made in the use of NIRS for ecological assessments and forage nutrient analyses (Foley et al. 1998). NIRS has been used successfully for the evaluation of forage nutrition and digestibility (McIlwee et al. 2001). Modeling of percent crude protein and acid detergent fiber using NIRS yielded results similar to other work examining forage of ungulates (Foley 2007). Use of NIRS provided equations sufficient to accurately predict both percent crude protein and acid detergent

fiber in CLMM should future work be conducted. The advantage of this approach is that it is much less expensive and a greater number of samples may be processed for the same cost.

## Conclusions

The population of bighorn sheep ewes and lambs in the BCNRA demonstrated the behavior expected by sheep that minimize risk of predation at the cost of maximizing nutrition. Nutritionally, CLMM seems to be variable spatially on this site. Given the importance of CLMM in the diet in the past (Kissell 1996), such spatial variation would lend itself to not searching for the most nutritious CLMM plants because this would increase the time spent foraging and thereby increase the risk of predation.

Counts provided serve as an index to the population size, but counts should be corrected based on a probability of detection. Estimates of probability of detection for counts are recommended if population estimates are not to be provided. Population estimates of bighorn sheep are recommended in place of counts currently used otherwise. Likewise, an estimate of recruitment should be emphasized in addition to the assessment of reproduction.

Monitoring of CLMM stands is warranted given the apparent change in decadence compared to the work by Peterson (1999). In addition, causes of CLMM mortality should be identified to determine if any management actions may to be taken to maintain this important forage species for resident bighorn sheep and wintering mule deer.

Future monitoring of percent crude protein and acid detergent fiber may be provided for CLMM at a reduced cost given the established NIRS models. A small sample ( $n \geq$

30) of should be collected and analyzed using wet chemistry to add to the current sample of 195 to account for annual variation. Nutritional assessment of areas not sampled in this study is recommended given the spatial variation in nutrition of CLMM.

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